MANULEARNING: A KNOWLEDGE-BASED SYSTEM TO ENABLE THE CONTINUOUS TRAINING OF WORKERS IN THE MANUFACTURING FIELD

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ABSTRACT

The Teaching Factory is an emerging paradigm aiming to enforce skills and competencies of engineers and operators working in the field of manufacturing, through an alignment of the teaching and training activities to the needs of modern factories. In this research work, the Teaching Factory principles are applied to envision ManuLearning, a new interactive and explorative knowledge-based system, which aims at enhancing the workforce skills and competencies within the context of Industry 4.0, while developing an awareness campaign to newest technologies among Small and Medium-sized Enterprises (SMEs). This paper presents this envisioned system by mainly focusing on two key-aspects: (i) the elicitation of its major requirements; (ii) the design of the architecture, which highlights how to concretize the realization of a communication channel between the factory and education systems. Finally, a real case study is introduced in order to demonstrate the correctness and validity of the proposed system.

KEYWORDS

Teaching Factory, Knowledge-based Systems, E-learning, Semantic-Web, Mixed Reality

1. INTRODUCTION

Modern industries ask for more sophisticated technologies and methodologies in order to align production systems to the demanding requests of the market. In particular, the push to technological changes come from the mass customization phenomenon, which tries to deliver wide-market goods and services adapted to specific customer need, thus conceiving a thorough rethinking of products, production processes and systems. In this context, all employees are called to continuously align their skills and competencies to the changing requirements of modern factories. This need can be supported by means of a continuous training path, which starts within courses offered by academic programs and continues in the real workplace. Among their main significant features, these courses allow to promote new contents, which evolve as technology advances and new market needs arise. In this regard, the training path can be driven by the growing paradigm of the Teaching Factory, which is specifically linked to manufacturing education. Its major scope is to align manufacturing training and teaching to the need of an increasingly complex scenario in industry (Chryssolouris et al. (2016); Rentzos et al. (2014)). Thus, the Teaching Factory turns traditional workplace into a life-long learning educational place, bringing several advantages. In this regard, Figure 1 reports an overall overview of the major advantages brought by the adoption of the Teaching Factory (internal circle) and the technologies considered enabling for the Teaching Factory (external circle). Besides the advantage to promote a continuous training environment inside the Factory, the concrete realization of the Teaching Factory also leads to beneficial results outside the factory by making affective a process of knowledge transfer based on a two-way channel, which includes: Factory-to-Classroom and Academia-to-industry communication paths (Chryssolouris et al. (2016)). From the one side, Factory feeds classroom with real world problems and solutions, which equip students with practical and useful skills, and addresses topics that are relevant and applicable to their lives outside of school, thus promoting an authentic learning instructional approach (Donovan et al. (1999); Burke (2009)). On the other side, the Academy feeds factory with innovations and research outcomes, which can be demonstrated and tested inside the factory. Such links

together contribute to realize the notion of knowledge triangle, which refers to the interaction among the key concepts of research, education and innovation, i.e. the major key drivers of a knowledge-based society. The European Union has adopted the notion of knowledge triangle to better link together these key concepts, with research and innovation already highlighted by the creation of the European Institute of Technology (EIT) (Figel (2006)). In addition, these key contexts are particularly relevant in the context of Italian Industry 4.0 initiatives, as their inclusion in the scope of Call "Centri di competenza ad alta specializzazione"[1] (hereinafter mentioned as Competence Centers) launched by the Italian Ministry of the Economic Development can demonstrate. According to the Competence Centers Call, the overall goal of this study is exploring the potential of the technologies related with Industry 4.0 (Hermann et al. (2016)) as enabler to realize the Teaching Factory. Specifically, this paper presents ManuLearning, a new interactive and explorative knowledge-based system, which aims at enhancing the workforce skills and competencies within the context of Industry 4.0, while developing an awareness campaign to newest technologies between SMEs as expected from the Competence Centers Call. In particular, by focusing on a specific Industry 4.0 technology (digital factory synchronized with the real factory), ManuLearning explores better and more efficient ways to enhance multi-stakeholder partnerships to reduce skills imbalances in Industry 4.0 technologies.

To realize the Teaching Factory, ManuLearning leverages e-learning and e-enhanced learning methodologies (Dougiamas and Taylor (2003); Hiltz (1986)). The latter are combined within a Visual-based Manufacturing approach (Khan et al. (2011)), supported by Mixed Reality (MR) applications and tools (Silva and Sutko (2009)), together with intelligent human-computer interaction systems. In addition, behind ManuLearning there is a Knowledge-based system, which is used to formalize and mediate the information coming from different actors involved by exploiting *de facto* standards and tools of the semantic web (Caldarola and Rinaldi (2016a,b,c); Modoni et al. (2015)). The focus of the work is mainly on three aspects: (i) the user requirements of the envisioned system, i.e., the definition of the workers interactions (GUI, Inference Rules) with machines and processes; (ii) the concrete instance of an architecture realizing the communication channel between the factory and the classroom; (iii) a real case study which is introduced to demonstrate the correctness and validity of the proposed system.

The remainder of this paper is organized as follows: Section II briefly reviews the existing works in the literature about the main topics involved in the current study; Section III elicits the ManuLearning's requirements. Section IV introduces the architecture of the systems, highlighting the technological pillars involved, while Section V presents a case study used to demonstrate the validity and opportunity to adopt ManuLearning. Finally, the last section draws the conclusions summarizing the main outcomes and outlining future lines of investigation.

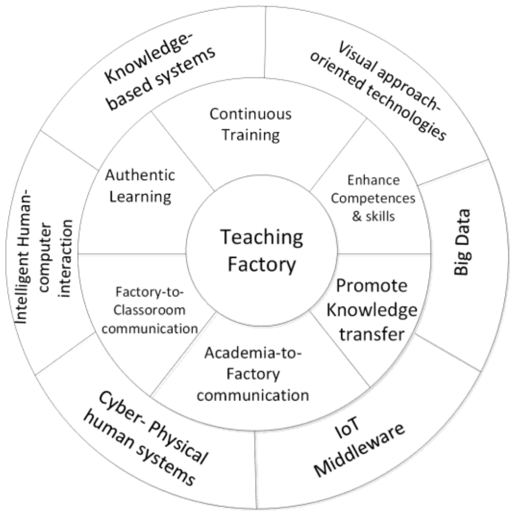

Figure 1. Teaching Factory benefits and technology panorama

[1] http://www.sviluppoeconomico.gov.it/index.php/it/incentivi/impresa/centri-di-competenza

2. OVERVIEW OF MANULEARNING SYSTEM

The subsequent sections provides the elicitation of the functional requirements for Manulearning System with a description of each requirement and possible technological solutions for the challenges they impose. Moreover, an overview of the Manulearning architecture based on different pillars is also discussed.

2.1 Elicitation of Requirements

A set of major functional requirements of the envisioned system, many of which are in line with the expectations of the above mentioned Competence Centers Call, are elicited in the following list.

R1. The system must support companies in assessing their level of digital and technological maturity in the context of Industry 4.0, according to specific evaluation criteria, through *ad hoc* surveys or questionnaire. The assessment concerns processes, technologies and knowledge workforce of the companies.

R2. The system must support training for companies, strengthening their technological skills in different enabling technologies of the Industry 4.0. Among such technologies the system will focus on a virtual factory model, namely the Digital Twin, constantly synchronized with the real factory. Although Digital Twin is not a new concept (Tomayko (1988)), only recently, progress in information and communication technologies has offered new opportunities to fully exploit its potential in various fields including manufacturing. Particularly, the industrial Internet of Things and the Big Data technological solutions (Caldarola et al. (2017)) can be considered enabling technologies for the effective implementation of the digital twin, whose potential has also been recently analyzed in many scientific articles (Kuts et al. (2017)). The aim of the proposed system is enhancing in particular the understanding, by the users, of the concrete benefits related to the adoption of the Digital Twin. In this regard, the system must support the possibility of testing the course contents by simulating variations with or without the new technology, thus highlighting performance and benefit indicators. In particular, the system must demonstrate the benefits, mainly in terms of reduction of errors and downtime, better quality of the production, lower costs and waste, greater functionality of products and services.

R3. The system must be able to manage, i.e., model, organize, visualize, etc., the following informative resources for the Teaching Factory: 1) Learning modules: all learning activities needed by the worker to be able to accomplish a specific task according to her/his role; 2) Production process tasks: all information concerning the production systems and processes, i.e., which are the task involved in each production process life cycle phase, the production system and the final product with its parts; 3) Companies Workers profiles: it includes biographic info, disabilities or impairments, work aspirations and attitudes, training activities and courses the worker has already taken part, his/her skills and responsibilities. The system must also clearly show the links existing between each pairs of informative resources described above. In this regard, a key feature of the environment is its capability to infer worker skill and competencies needed to accomplish a specific task. In addition, the system can infer the learning modules essential to accumulate these competencies, which can be virtually explored under the form of multimedia links.

R4. The Learning modules are conceived as both offline and online learning contents. In the former case, they are used as a mean for instructing workers to accomplish a job before starting the actual job itself (in other words they are used offline in the classroom for training workers by exploiting simulation tools, gamification, multimedia learning contents, and so forth), while, in the latter case, they support them while they are working on the piece at the shop floor (for example, by using Augmented Reality tools, chatbot, online helpdesk, etc.). Thus, the system must be able to exploit the learning modules for both the above mentioned purposes.

R5. The system must promote knowledge elicitation best-practices among workers. This means that it must provide the way workers can share and explicit the knowledge they have acquired (their expertise) in performing their job over the time. Communities of practice or web forum can be used for this scope.

R6. The system must demonstrate how by enabling context-awareness capabilities, i.e., dealing with linking changes in the environment according to various categorizations of context types, such as, location, identity, activity and time (Abowd et al. (1999)), or, furthermore, according to user and role, process and task, location, time and machinery to cover a broad variety of production process scenarios (Kaltz et al. (2005)), can lead to great advantages in improving the workers efficiency and the production process overall efficiency. Data about workers actions, behaviors and results in approaching the task to accomplish must be

constantly monitored online (as a continuous data stream) in order for the system to react real-time (or near real-time) to changes.

R7. The system must be able to update the learning modules according to advances in production systems technologies or changes in production processes, which may require retraining workers, and warn the latter in the case. In addition, it must assess the effectiveness of the training activities (in terms of formative success).

2.2 ManuLearning Architecture

Figure 2 shows the pillars underpinning the ManuLearning system. At the base of the system there is a collection of study cases, each one is implemented by means of a demonstrator, which are showed in order to highlight the importance of adopting the newest Industry 4.0 technologies in a modern factory scenario. How and to what extent companies, especially the SMEs, acknowledge such innovations is subject to evaluation through a set of surveys able to assess the maturity grade of a company with respect to a particular technology. This function of the system lays on top of all the technological pillars in the Figure. 2 Finally, at the top of ManuLearning is the concrete realization of the Digital Twin, i.e., the result of adopting and effectively use the framed technologies, after an effective training activity and an awareness campaign between SMEs. In each of the following list items, the corresponding technological pillar will be described and discussed:

P1: Mixed Reality Environment. According to req. R2, its scope is to support training activities and demonstration scenario, thus highlighting the importance of adopting / implementing the Digital Twin in the context of Industry 4.0. The environment requires the use of typical AR equipment (e.g., head-mounted display units such as HoloLens), which enhance the training experience of workers by merging the real and virtual worlds to produce a new environment where physical and digital objects co-exist and interact in real time.

P2: Factory Telemetry. It fully synchronizes the real and virtual world (Modoni et al. (2016)) by leveraging proper technologies to support both the near real time data processing and the storage of data to be used for post-processing analytics (Kuts et al. (2017)).

P3: Knowledge Model. ManuLearning system exploits the Semantic Web *de facto* standard languages, such as RDF (Resources Description Language) and OWL (Ontology Web Language), in order to formalize, in a shareable and understandable model, all the knowledge and in particular the logical links existing between skills and competencies, production process tasks and technological solutions able to support the workers in accomplish their tasks. Specifically, this pillar includes three major models. The first is the *Digital Model of the Factory*, which formally represents the concepts and logical links between concepts characterizing the Factory representational model (Modoni et al. (2017a)). The second is the *Evaluation Model*, whose aim is assessing the level of technological and digital maturity of the manufacturing companies. It intends to be a common definition and conceptual framework for specific skill requirements for KETs (with a particular attention to multi-KETs) leveraging the specifics described in a study funded by European Commission (Skill for KET, 2017). Finally, the third model is the *Virtual Individual Model of workers* (VIMW) involved in the production process and their skills and competencies.

P4: Knowledge Repository. The goal of this pillar is managing and storing the knowledge model and its instances, leveraging a well-proven RDF store.

P5: Artificial Reasoner. According to the req. R1, it assesses the level of technological maturity of a manufacturing company in the context of Industry 4.0. Leveraging the underlying digital model (P3), the level of maturity is inferred through predefined rules which process the results of *ad doc* surveys based on specific evaluation criteria (Modoni et al. (2017b)).

P6: Help desk Module. This pillar aims to support users during their activities, by putting at the same level humans, avatars and chatbots (a kind of chat based on Artificial Intelligence that continuously learn from acquired data). In particular, it allows to connect a network of workers from different locations (maybe employed in different companies) with a network of chatbots. Thus, the workers can synergistically improve each other by exchanging useful information.

P7: Open Learning Modules. According to the req. R5, they encourage the community to provide suggestions and feedback and support scholars or students with real-life use cases, thus creating a channel between factories and the classroom, which can incorporate valuable contents in their courses programs and train competent people ready for the job market.

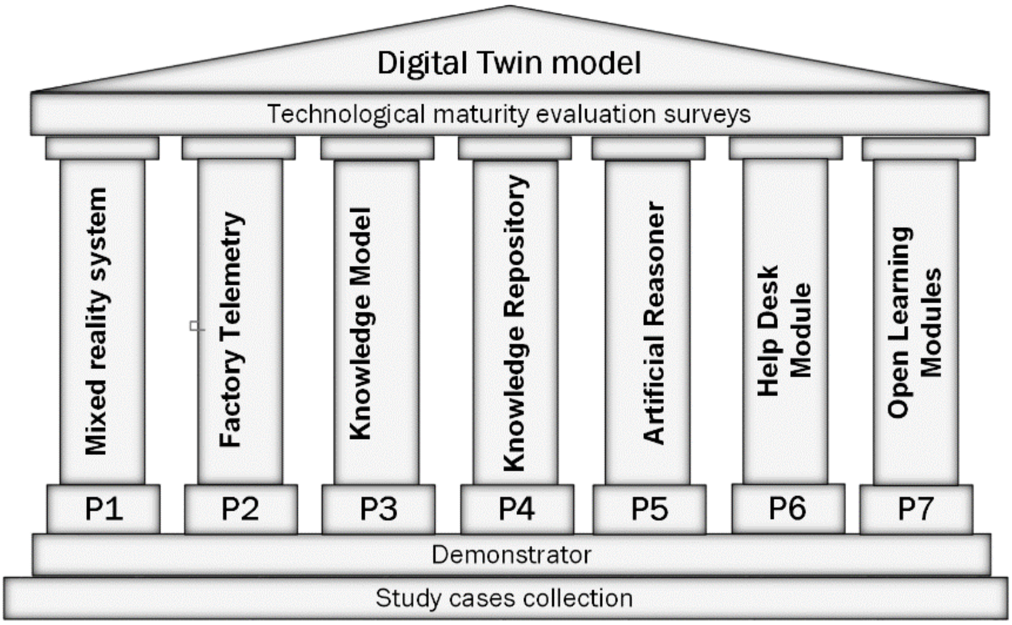

Figure 2. ManuLearning architecture pillars

3. THE PROOF OF CONCEPT

A demonstrative production line set in a factory plant which produces wooden furniture offers a valid scenario to test the proposed system. In particular, the demonstrator allows to illustrate to a potential stakeholder the benefits of a virtual factory model (Digital Twin) synchronized with the physical world of the shop floor. The relevance of the synchronized Digital Twin within the case study is demonstrated through two different use cases. The first one allows the workers to visualize in real time significant information related to the tasks they are approaching, while the second one illustrates how an e-enhanced learning activity can augment the efficacy in the training process of workers thanks to the support of the MR environment (Pillar 1).

The first use case can be significant for any modern manufacturing company where the high variety of products deriving from the mass customization may require an extra effort for workers in order to deal with the change of work instructions. Indeed, in traditional approach, the adoption of new technologies is limited while it is typical the use of hard copy manuals which force the operator to continuously check out the instruction sheets, due to the differences among assembling sequences of different products models. This approach can lead to a waste of time, which can significantly grow depending on worker experience and on the frequency of production of different models. Conversely, the proper adoption of a synchronized Digital Twin can provide just-in-time information delivering, following the principle of transferring the right information at the right person at the right time. In addition, this information can be processed to apply some corrective actions to the real factory. Within this use case, it is possible to simulate different layouts of the factory exploiting historical telemetry files, thus showing the possibility of comparing the current performances and predicting faults. In this context, the system must be able to react to mistakes made by workers or machineries disservices or failures during the completion of the task and recommend the right intervention in order to remedy such errors / disservices. What we expect from the implementation of the synchronized digital twin within this use case are the following benefits: reducing mistakes from employees and suppliers; reducing search time in navigating the facility and locating tools, parts and supplies; reducing unnecessary human motion and transportation of goods.

The second analyzed use case derives from previous experiences gained in the field of Visual Advanced Manufacturing (Capozzi et al. (2014)). This use case is mainly relevant for companies where the workers are typically not interchangeable in the assembly line as they are typically formed for accomplishing a specific task (e.g., drilling, assembly of parts, cutting, etc.). For this reason, job rotation is not applicable, and thus, the company has great difficulty in distributing the workload, for example, when it must deal with peaks of requests for a certain product (requiring specific workings) or in the case of unavailability of some resources. Moreover, the lack of a proper job rotation may result frustrating for worker who is forced to perform the same operations all the time. The main benefit of the adoption of the synchronized virtual factory in this case consists in the time reduction for employee orientation and training, thus increasing productivity supporting sustainability, mainly from a social perspective. Within the envisioned system supporting this use case, once the operator is ready to start his work, he approaches the workstation and is immediately recognized through proximity sensors like eBeacon. By accessing his profile, represented in the VIMW model, the system is able to verify if the operator properly fits to do a certain job over a certain machine. Under these conditions, leveraging this approach, workers will no longer perform their tasks routinely; instead, they will have to undertake varied and mostly unstructured tasks, depending on the needs of the dynamically changing production process. Teams should/will include flexible and remote ways of working and interacting with the systems as well as with other workers. As shown in Figure 3, the two case studies involve different actors and components: the operators, an AR equipment, the Factory Telemetry and the virtual models. It also involves different technological solutions which support such components: a Mixed Reality System, with annex headset or visors like the Oculus Rift. In this regard, the Mixed Reality System, implemented through the FactoryIO API[2], is used to augment the capabilities of the real components of the factory. Moreover, this technology contributes to propose virtually some real components or some parts that are not easily reproducible within the real demonstrator. In addition, the use case are supported by a distributed sensor network, which is spread throughout all machinery and operators, intelligent software robots like chatbot able to assist the human operators in accomplishing their tasks in a high level of abstraction.

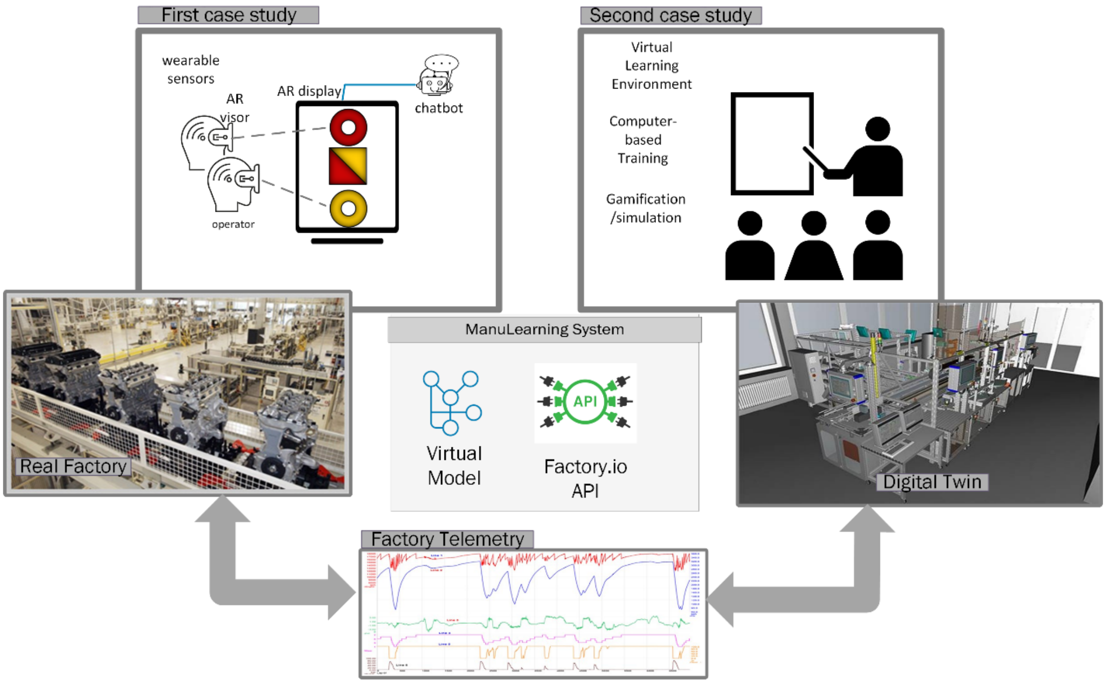

Figure 3. ManuLearning system and case studies

[2] https://factoryio.com/

4. CONCLUSION

In this work, a knowledge-based system, namely ManuLearning, has been proposed in order to enhance the continuous training and skills of workers within the Teaching Factory context. The conceived system has put in evidence how thanks to the cutting edge technologies belonging to the panorama of Industry 4.0, specifically those concerning the Visual-based manufacturing and e-enhanced learning, it is possible to align the competencies and skills of workers to the needs of modern factories. ManuLearning comes with a knowledge model that allows to evaluate the technological maturity of SMEs and a couple of study cases, whose scope is to demonstrate the advantages, in terms of performances and return of investments, that SMEs can gain from the adoption of the sponsored technologies, thus promoting such technologies among entrepreneurs and knowledge workers. The technological and founding pillars underpinning the system have been thoroughly presented together with the requirements expected from the fully exploitation of ManuLearning. Future lines of researches will go in the direction of enlarging the set of study cases with the adoption of more sophisticated and complete knowledge models of the smart factory also by applying the proposed system to other industrial scenarios.

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